

XIV. SIGNAL PROCESSING*

Academic and Research Staff

Prof. A. G. Bose
Prof. J. D. Bruce
Prof. D. E. Nelsen

Prof. A. V. Oppenheim
Prof. C. L. Searle
Prof. H. J. Zimmermann

Dr. M. V. Cerrillo
Dr. V. N. Kuleshov

Graduate Students

M. P. Bruce-Lockhart
S. A. Hendryx

R. M. Mersereau
S. G. Peltan

M. R. Sambur
J. L. Veranth

A. POWER PROCESSING BY TWO-STATE MODULATION

By processing a signal as a two-state waveform, high system efficiency may be achieved, since power devices can be operated as switches. Modulation techniques that allow the original signal to be extracted from the two-state waveform by lowpass filtering have particular value for power processing. One such modulation technique has been suggested by A. G. Bose.¹ This system employs feedback around a lowpass filter and hysteresis switch to cause switching as the filter output varies between $V_i + V_h$ and $V_i - V_h$ (Fig. XIV-1).

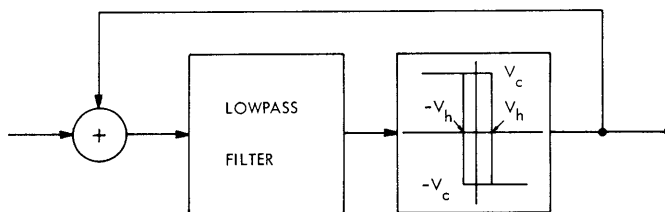


Fig. XIV-1. Two-state modulation system.

A particularly valuable application of this system has been proposed by T. A. Froeschle.² If the controlled variable is current, two important features are obtained (Fig. XIV-2). If the input to the current-controlled system is constrained within a set range, the output current may be limited to the output device ratings, thereby ensuring that the system cannot be destroyed by a pathological load. Since the output current is controlled, any filter inductor placed in series with the switch output will not appear in the system terminal relations, thereby reducing stability problems in any additional feedback loop.

This research has been concerned with modeling and optimizing this type of

*This work was supported by the Joint Services Electronics Programs (U. S. Army, U. S. Navy, and U. S. Air Force) under Contract DA 28-043-AMC-02536(E).

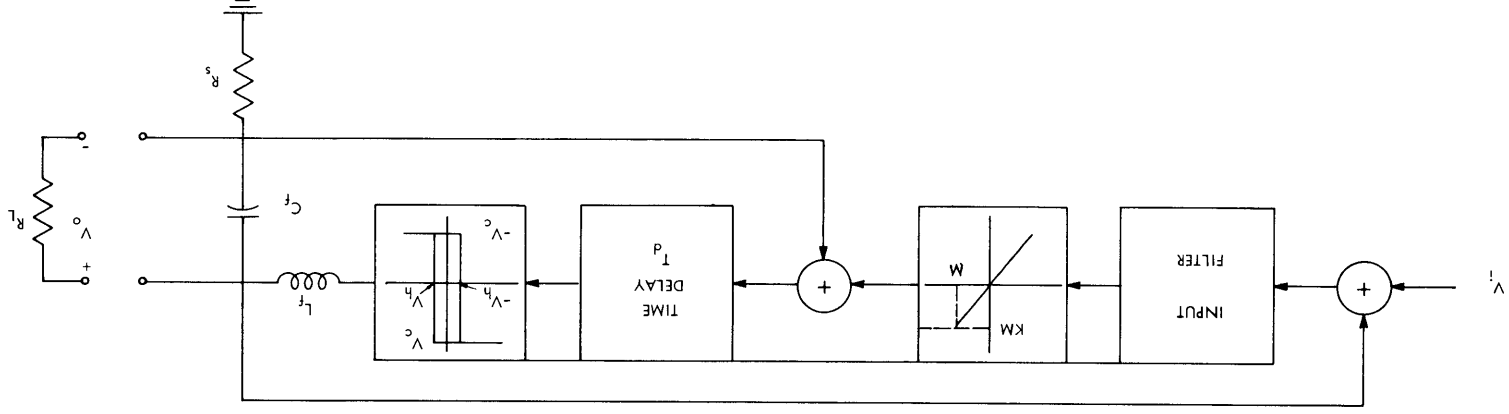


Fig. XIV-2. Complete current-controlled voltage amplifier.

current-controlled system for wide bandwidth power amplification. Since the switching frequency itself imposes a signal-bandwidth limitation, a zero signal switching frequency of roughly five times the signal bandwidth, B , is required. The output network imposes a power-bandwidth limitation. For a given power bandwidth, B_p , the optimum output network has been found to be³

$$L_f = 0.26 R_L / B_p \quad C_f = L_f / R_L^2.$$

Switching frequency stability for load variations could be obtained in low-bandwidth systems by making C_f large. This would fix the switching frequency as a function of output voltage:

$$f = f_o \left(1 - \frac{V_o^2}{V_c^3} \right) \quad f_o = \frac{R_s V_c}{4V_h L_f + 4T_d R_s V_c}.$$

Since the bandwidth requirements limit the capacitor size, the switching frequency depends upon the load. By recognizing that the load voltage (though not the output current) is nearly sinusoidal, the switching frequency may be found for any linear load by expansion of the output V - I characteristic of the amplifier in a Fourier series and equating it to the load impedance. The important result is that by attempting to resonate the load with the output network, the switching frequency may be forced away from f_o by a maximum of $0.556 B_p$. This typically gives switching frequency stability of better than 10%. Thus, the current source may be modeled in the signal band as a current source shunted by a resistor and capacitor (Fig. XIV-3). The method of analysis used above yields a total harmonic distortion of less than 2%.

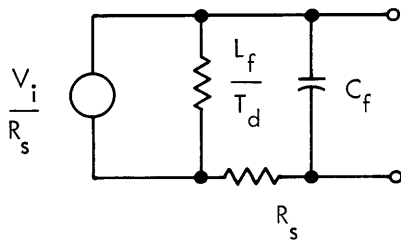


Fig. XIV-3. Model of the current source.

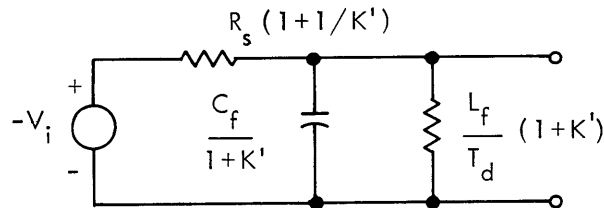


Fig. XIV-4. Model of the complete amplifier.

Without any input filtering, the amplifier with an external voltage feedback loop is stable for all linear realizable loads, and may be modeled as shown in Fig. XIV-4.

(XIV. SIGNAL PROCESSING)

$K' = K$ for small values of K , but as K is increased so that the switching signal drives the input amplifier into limiting, K' approaches its maximum effective value.

$$K = 6.07 \frac{B^2}{B_p^2} \frac{R_s}{R_L}.$$

Thus improved performance of this optimized system may be obtained only at the expense of power bandwidth relative to signal bandwidth.

Further investigation of this system has been performed with the aid of a computer simulation. This detailed simulation in the time domain and breadboard testing have confirmed the analysis.

J. L. Veranth

References

1. A. G. Bose, "A Two-State Modulation System," Western Electronic Show and Convention, San Francisco, August 20-23, 1963, Sec. 7.1.
2. T. A. Froeschle, "Two-State Modulation Techniques for Power Systems," Technical Report ECOM-02282-1, June 1967.
3. J. L. Veranth, "Analysis of a Current-Controlled Two-State Modulation System," S.M. Thesis, Department of Electrical Engineering, M.I.T., June 1970.

B. WAVEFORM ENVELOPE DETECTION

This work is an extension of the work done by M. V. Cerrillo¹ on the detection of musical notes. Such detection is the necessary first step in a number of experiments involving electronic alteration of the character of a recorded musical passage.² It also has implications for signal separation and possibly for recognition.

The circuits, which were suggested by Dr. Cerrillo in conversations with him, involve two envelope detectors, one with a fast rise time and a slow decay and the other with a slower rise time and a slow decay. Taking the difference between these two envelope detectors, we obtain an output at the beginning of each note. The circuit for such a note detector is shown in Fig. XIV-5.

Unfortunately, such a circuit does not do a very effective job of discriminating between two different types of notes; a piano note and a violin note, for example. To provide additional discrimination, the decay of the detected note was considered also. Two additional detectors were built (as shown in Fig. XIV-6) with considerably faster decay times than the first pair had. By combining these four detectors as shown in Fig. XIV-6, it is possible to discriminate between a piano note and a

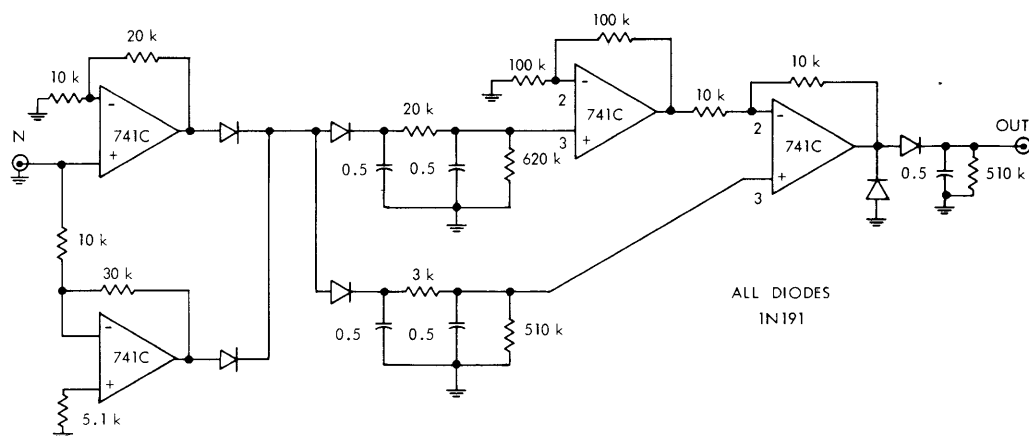


Fig. XIV-5. Note detector circuit.

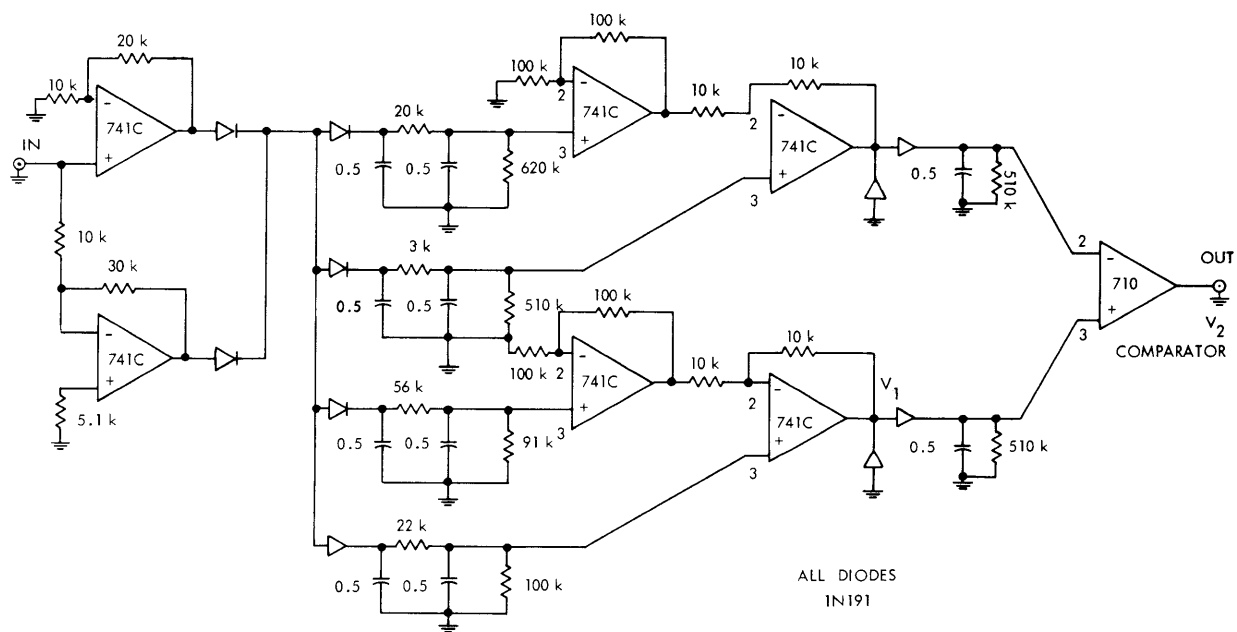


Fig. XIV-6. Discriminator circuit.

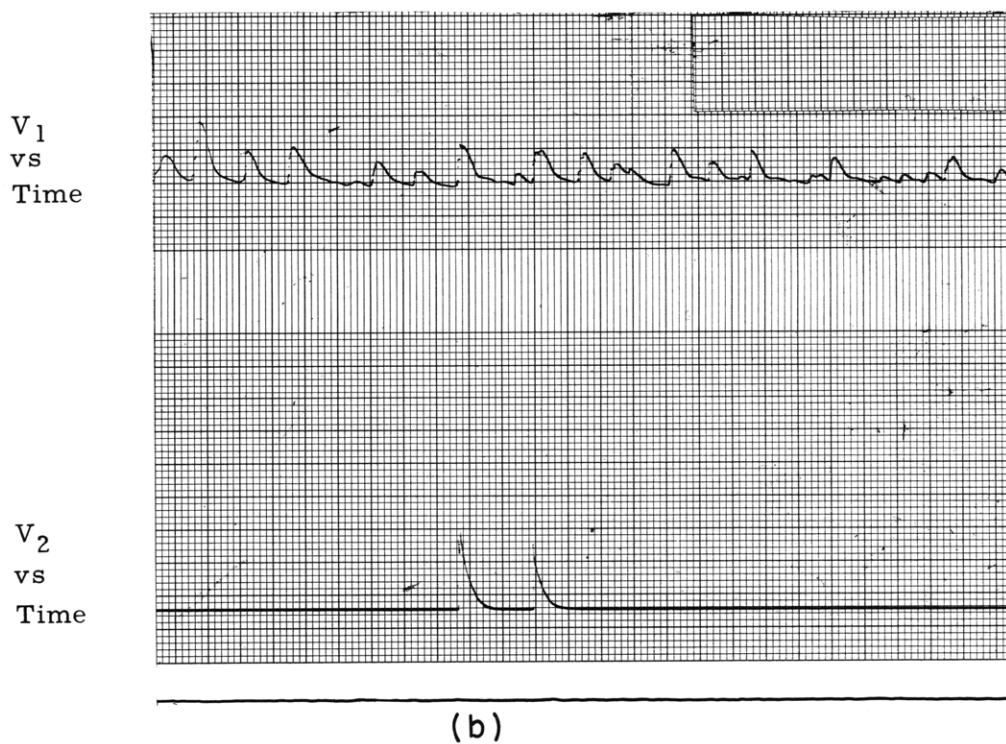
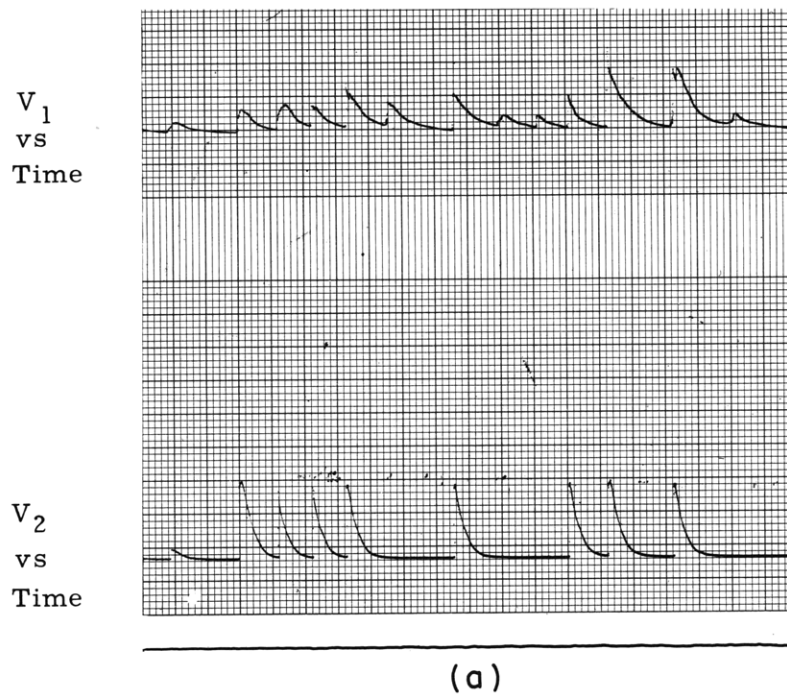


Fig. XIV-7. Waveforms of the discriminator circuit.
(a) Piano passage. (b) Violin passage.

(XIV. SIGNAL PROCESSING)

violin note approximately 80% of the time, as can be seen from Fig. XIV-7. In this figure, the upper graph is the output of the first difference amplifier in Fig. XIV-6, and the lower trace is the output of the final comparator. The circuit detected 8 of 13 piano notes, while responding to only 2 of 21 violin notes.

A. J. Tortolano

References

1. M. V. Cerrillo, "Rhythm Extraction in a Musical Composition," Quarterly Progress Report, Research Laboratory of Electronics, M.I.T., July 15, 1957, pp. 93-100; for the statement of this problem and other basic considerations, see Quarterly Progress Report, April 15, 1957, pp. 101-102.
2. M. Bruce-Lockhart, "Time-Domain Synthesis," Quarterly Progress Report No. 96, Research Laboratory of Electronics, M.I.T., January 15, 1970, pp. 256-258.

